10-1900

Fertilizer Experiments

University of Tennessee Agricultural Experiment Station

BULLETIN

OF THE

Agricultural Experiment Station

OF THE

UNIVERSITY OF TENNESSEE

MORRILL HALL

VOL. XIII OCTOBER, 1900 No. 3

FERTILIZER EXPERIMENTS

—ON—

1 POTATOES

2 CORN

3 COW PEAS

4 PEANUTS

AND

Effects of Fertilizers on the Germination of Seeds

THE AGRICULTURAL EXPERIMENT STATION

OF THE UNIVERSITY OF TENNESSEE

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FERTILIZER EXPERIMENTS DURING 1900

CHARLES A. MOOERS

INTRODUCTION

Among the farmers a decided diversity of opinion exists as to the profit from the use of fertilizers. Some who have relied almost exclusively upon them to maintain or permanently to increase soil fertility have been disappointed and condemn their use altogether; others have used them with highly satisfactory returns, largely because they have at the same time not neglected to manure their fields and have grown much clover and peas to be fed on the place.

Some of the following experiments were made in order to determine the kinds of plant food—whether phosphoric acid, potash, or nitrogen—and the combinations most needed by different soils; others were planned to be of more general application. To this latter class belong in particular the cow pea experiments and the comparisons between cotton-seed meal and nitrate of soda as sources of nitrogen for potatoes.

The chemical analyses of potatoes and corn emphasize the fact that the quality of the crop as well as the yield should be considered in the fertilizer question, while the soil analyses give additional weight to some of the field tests.

SOME GENERAL CONSIDERATIONS

Of all the kinds of plant food in the soil, nitrogen, which is generally known in the form of ammonia, is rightly considered the most important and the most difficult with which the farmer has to deal. This is true for at least three reasons. First, it is by far the most expensive element to replace. For example, it would require at present prices about 30 cents to replace the nitrogen removed by a bushel of wheat, while six and one-half cents would replace both the phosphoric acid and the potash. Second, it is the form of plant food most easily lost from the soil by leaching, and the only one that may escape into the air. Third, when present in superabundance it acts injuriously by producing an excessive growth of stem and leaf; the wheat lodges and the sweet potato goes to vine. In this state the nitrogen problem is of more than usual importance on account of its being deficient in most of the soils. In too many instances only the six and one-half cents worth of the mineral elements, phosphoric acid and potash, has been replaced while the 30 cents worth of nitrogen has almost been ignored. In fact, this is the most important reason for the unsatisfactory results when fertilizers alone are relied upon to maintain soil fertility. For increasing the total nitrogen supply in his soil the farmer has only two means. One is to grow leguminous crops, such as cowpeas and clover, which may either be fed and the manure returned to the land, or be turned under as green manure; the other is to bring on the farm nitrogen from the outside which may be contained either in nitrogenous feeds, such as cotton-seed meal and bran, or in nitrogenous fertilizer materials, such as cotton-seed meal, blood, and tankage. All these methods are advised, and the results of the fertilizer experiments with potatoes show that when this crop can be disposed of at a reasonable price it may be used to build up a soil in this element as well as in the other elements of plant food by the aid of fertilizers alone. It should be emphasized here that the true way to look upon fertilizers is not as stimulants to the soil, for that implies harmful after effects, but as plant food which should be turned only to good account.

One of the many problems of greater or less importance is the relative worth of nitrogen from different sources. In particular we want to know what it may be expected to do the first season. To illustrate by two extremes, the nitrogen of sodium nitrate is considered to have an availability of 100 per cent, that is, it is ready, without undergoing any change, to be used by the plant; while the nitrogen found in leather would not all be used for many years. Various tables have been published showing the relative availability of nitrogen from different substances. The following is a standard German table by Wagner:*

Nitrate of soda	100
Sulphate of ammonia	88
Blood meal	69
Castor pumice	67
Green crops plowed in	68
Horn meal	63
Steamed bone meal	61
Flesh meal	54
Wool dust	33
Stable manure	32
Leather meal	20

Wagner states that of course the figures are not absolute and that they would be changed by climate, character of soil, and kind of crop.

A question of considerable importance to the southern farmer is the value under field conditions of the nitrogen of cotton-seed meal. How does it compare, unit per unit of nitrogen, with sodium nitrate, and would the nitrate be a good material to mix with it? As the potato plant is very sensitive to all kinds of manuring it was taken to help answer these questions and also to test other soil needs.

EXPERIMENTS WITH FERTILIZERS ON POTATOES

Experiments on potatoes were made in two places. Series (1) was on a dolomite soil (upland "white gravelly"), which was known both from previous crops and from chemical analysis to be very deficient in plant food. So far as known, it had never been manured or fertilized, with the exception of a single light dressing of acid phosphate and potash. In texture and location, however, it was considered to be especially well adapted to the objects in view. Series (2) was also on a dolomite soil, but one that had been frequently manured and which was therefore much more fertile than the preceding.

*Storer's Agriculture, Vol. II, p. 53.

SERIES (1)

These experiments were located on Black Oak ridge, about five miles north of Knoxville. The soil was the "white gravelly" clay, which is characteristic of the dolomite ridges throughout East Tennessee, and had produced scanty crops of corn and wheat for fifty or more years.

PREPARATION OF SOIL AND APPLICATION OF FERTILIZER—The land had been plowed to a depth of six to seven inches a few days before planting, and was put in better condition by two harrowings, after which it was laid off with a large turn plow into rows three feet apart. Plots 1 to 6 were 1-16 of an acre each and were made to contain five rows. Plot 7 was 1-40 of an acre with two rows. Plot 8 was 1-32 of an acre with three rows. Except the nitrate of soda for plots 1, 4 and 7, all the fertilizer materials were weighed out separately for each plot, and after being well mixed the amount for each row was weighed out and applied separately. The fertilizer was then mixed with the soil by running a "bull tongue" through it once. The seed, good sized Burbanks, cut to one and two eyes and used at the rate of 10 bushels to the acre, were then dropped and covered, after which one-half of the nitrate for plots 1, 4 and 7 was applied along the rows, the amount for each row being weighed and applied separately. On May 12, after the potatoes had been up about two weeks, the remainder of the nitrate was applied in the same manner.

NOTES—Between April 3 and May 1, when the plants were just up, there were numerous heavy showers, which probably carried a large part of the nitrate out of the soil. However, the plants which received the larger applications were the more vigorous. Up to May 23 the plants fertilized with cotton-seed meal had in every instance made a decidedly stronger growth than those fertilized with nitrate of soda. At this date the plants of plot 6, which received no potash, had made slightly the best growth of all and the leaves were the darkest colored. After May 23, the plants of the nitrate plots took on a richer green and made a decided increase in growth until they nearly equaled in appearance those fertilized with cotton-seed meal. During May there was practically no rain, excepting a light shower on the 23, so that the plants suffered from lack of moisture. In June there were long continued rains and cloudy weather followed by hot, dry weather, which resulted in the plants being sun-scalded, so that by July 10 nearly all were badly affected, and by the first of August nearly all were dead. It was noticed in particular that the plants of plot 5, which received no fertilizer, were the first to die; next were those of plot 6, which received no potash, and of plot 8, which received no phosphoric acid; then followed those fertilized with the complete fertilizers containing cotton-seed meal; and the last to succumb were those fertilized with a complete fertilizer containing nitrate of soda, plots 1 and 4.

TABLE I. RESULTS PER ACRE FROM SERIES (1) OF FERTILIZER EXPERIMENTS ON POTATOES

Plot	Fertilizer: Kind	Fertilizer: Lbs.	Yield: (a) Salable	Yield: (b) Culls	Increase from fertilizer. Salable	Cost of fertilizer	Profit and loss from use of fertilizer: Profit	Profit and loss from use of fertilizer: Loss
			Bu.	Bu.	Bu.			
1	Nitrate of soda...... Acid phosphate...... Muriate of potash...	240 500 180	84.0	9.0	69.4	$14.50	$20.20	......
2	Cotton-seed meal.... Acid phosphate...... Muriate of potash...	540 500 180	116.5	7.0	101.9	15.25	35.70	......
3	Cotton-seed meal.... Acid phosphate...... Muriate of potash....	405 500 180	104.8	10.6	90.2	13.56	31.54	......
4	Nitrate of soda...... Acid phosphate...... Muriate of potash....	180 500 180	71.2	10.9	56.6	13.00	15.30	......
5	No fertilizer...........	......	16.9	9.3	......	......	......	......
6	Cotton-seed meal.... Acid phosphate......	405 500	90.8	9.9	76.2	9.06	29.04	......
7	Nitrate of soda...... Acid phosphate......	180 500	43.0	8.0	28.4	8.50	5.70	......
8	Cotton-seed meal.... Muriate of potash....	540 180	27.1	4.0	12.5	11.25	......	$5.00
9	Cotton-seed meal.... Nitrate of soda...... Acid phosphate...... Muriate of potash....	405 60 500 180	82.0	14.4	67.4	15.06	18.64	......
10	No fertilizer...........	......	12.3	5.6	......	......	......	......

In calculating the profit and loss for all the experiments the fertilizer materials were valued according to the local prices in the Knoxville market, as follows: Acid phosphate, 16 per cent available phosphoric acid, $16.00 per ton; muriate of potash, two and one-half cents per pound; nitrate of soda, two and one-half cents per pound; cotton-seed meal $1.25 per cwt. The salable potatoes were valued at 50 cents per bushel, but no allowance was made for the culls.

SERIES (2)

These experiments were carefully carried out by Mr. C. O. Hill, of the chemical department of the University. The soil used was of the same general character as that of the preceding series, except that it had been frequently manured until the previous season, when it was cropped without manure or fertilizer. The preparation of the soil, the amount of seed used, etc., and the manner of applying the fertilizer were about the same as in series (1). Each plot was 1-20 of an acre, having four rows three feet apart and 189 feet long. The date of planting and applying the fertilizer was March 28. The second application of nitrate of soda was made May 14. The same conditions of weather prevailed for this series as for the preceding, with the exception of one heavy shower in May which series (1) did not receive.

TABLE II. RESULTS PER ACRE FROM SERIES (2) OF FERTILIZER EXPERIMENTS ON POTATOES

Plot	Fertilizer: Kind	Fertilizer: Lbs.	Yield: (a) Salable	Yield: (b) Culls	Increase from fertilizer. Salable	Cost of fertilizer	Profit from fertilizer
			Bu.	Bu.	Bu.		
1	Cotton-seed meal Acid phosphate Muriate of potash	400 400 180	150.7	9.3	87.7	$12.70	$31.15
2	Nitrate of soda Acid phosphate Muriate of potash	180 400 180	127.5	12.7	64.5	12.20	20.05
3	No fertilizer	......	63.0	12.7	......	......	......
4	Nitrate of soda Acid phosphate Muriate of potash	180 400 90	92.0	14.0	29.0	9.95	4.55
5	Nitrate of soda Acid phosphate	180 400	108.0	16.3	45.0	7.70	14.80
6	Cotton seed meal Nitrate of soda Acid phosphate Muriate of potash	200 90 400 180	122.0	21.3	59.0	12.45	17.05

CONCLUSIONS AND REMARKS

NITROGEN—In both series it is apparent that all kinds of plant food were needed and could be used with profit. While in every instance the cotton-seed meal gave more profitable returns than the nitrate of soda, the results should not be interpreted to mean that the nitrogen of the meal is the more readily available, for it is evident that there is at least one drawback to the use of the nitrate, and that is its liability to be washed out of the soil before it can be used by the plants. We would conclude therefore that the first application of nitrate should be made after the plants are up rather than at the time of planting. It is probable, judging from the results of other experimenters, that had the first month after the seed was planted been dry the yields would have been reversed, for in that case the nitrate would not have been washed out of the soil or the cotton-seed meal have become as available, since wet weather materially hastens its decomposition. The results assure us, however, that the nitrogen of the cotton-seed meal is quick in its action, so that in plot 9 there was no advantage in mixing with it the more readily available nitrate of soda.

In series (1) the yield increased in proportion to the amount of cotton-seed meal used, but the experiments were not sufficiently extended to determine the limiting amount which could have been used with profit. On this particular soil probably a heavier application could have been made to advantage without at the same time increasing the amount of either phosphoric acid or potash. On more fertile soils this might not be the case, so that it is not possible to say just how much should be used. From field experiments and from theoretical considerations it seems safe to conclude that a mixture of 540 pounds of cotton-seed meal, 500 pounds of high-grade acid phosphate, and 180 pounds of the sulphate or muriate of potash, is not overbalanced in nitrogen, but would be expected to make a profitable increase on any ordinary soil which is adapted to this crop.

PHOSPHORIC ACID—For Tennessee soils phosphoric acid is, probably more than any other, the grain and fruit producing element needed. The effect of its absence is plainly seen in plot 8, where only muriate of potash and cotton-seed meal were used. In this connection it may be noted that cotton-seed meal is a complete fertilizer of itself, but overbalanced with nitrogen. Its average composition is about 7.0 per cent nitrogen, or 8.5 per cent ammonia, 1.8 per cent potash, and 2.9 per cent phosphoric acid. In plot 8, although there was a great excess of nitrogen, which is considered as the more especially leaf producing element, over the phosphoric acid, the plants made only a small growth of tops, corresponding with the small yield of tubers, and the experiment illustrates the fundamental importance of the mineral elements in order to the successful use of any nitrogenous fertilizer material.

POTASH—Scarcely any plant is more affected by a deficiency of potash in the soil than the potato. At the same time this seems to be the element least required by our soils. This is seen more clearly in series (2), where the plot which received no potash gave a larger yield than the adjoining plot, which received potash at the rate of 90 pounds to the acre. However, when we average the yields of the plots which received the full amount of potash with the plots which received no potash and half the full amount, we find that it was used with profit. In series (1) the value of potash is much more evident, but even here the substantial increase of 76.2 bushels per acre in plot 6 was made without it. From experiments recently made in Germany* the conclusion is drawn that muriate of potash of itself does not lessen the starch content of the potato, but that an impurity, magnesium chloride, which is often present, produces decidedly injurious results. Even if this impurity were absent, practically the same results would be expected, for the muriate of potash would combine with magnesia, which is always present in the soil, and form the injurious magnesium chloride. With sulphate of potash this would not be the case. In experiments made late this season, but which were spoiled by excessively dry weather, the indications were much in favor of using the sulphate. The crops harvested were 20 bushels to the acre from the plot fertilized with muriate of potash and 30 bushels from the plot fertilized with the sulphate. From the start the plants fertilized with the sulphate made a more vigorous growth than those fertilized with the muriate. More conclusive results are hoped for next season, but at present the sulphate is recommended rather than the muriate.

RESIDUES FROM THE FERTILIZERS—It is of importance to notice the amounts of the different elements removed from the soil. For example, let us take plot 2 of series (1). The total yield was 123½ bushels of potatoes, which would remove approximately the following amounts of plant food, stated in terms of the fertilizers used:

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*Landw. Vers. Sta. 54 (1900) No. 5-6, pp. 379-385.

The nitrogen in 324 pounds of cotton-seed meal.

The phosphoric acid in 68 pounds of acid phosphate.

The potash in 71 pounds of muriate of potash.

This shows that the soil was built up in all the elements of plant food, phosphoric acid and potash in particular, and means that the continued use of this fertilizer would overstock the soil, so far as profit is concerned, especially with phosphoric acid, the amount of which after two or three years could be reasonably diminished without fear of a decreased yield.

TABLE III. ANALYSES OF POTATOES

Variety	County where grown	Kind of fertilizer used	No. of plot in table I	Water	N-free extract and fat °	Protein	Fiber	Ash	Specific gravity
				%	%	%	%	%	
Burbank...	Cumberland	P K N* ..	....	80.99	16.11	1.39	0.47	1.04	1.071
Rural New Yorker....	Cumberland	P K N* ..	....	80.23	16.96	1.42	0.43	0.96	1.071
Bovee.....	Cumberland	P K N* ..	....	82.06	14.69	1.81	0.46	0.98	1.069
Average	for Cum. Co.	....	....	81.09	15.93	1.54	0.45	0.99	1.070
Burbank...	Knox.......	P K N ...	2	80.51	16.58	1.40	0.58	0.93	1.066
Burbank...	Knox.......	P K N ...	4	80.55	16.05	1.86	0.54	1.00	1.056
Burbank...	Knox.......	None	5	82.55	13.58	2.24	0.64	0.99	1.060
Burbank...	Knox.......	P N......	7	81.94	14.79	1.88	0.50	0.89	1.063
Burbank...	Knox.......	P N......	8	81.56	14.84	2.18	0.46	0.96	1.061
Average	for Knox Co.	....	....	81.42	15.18	1.91	0.54	0.95	1.061

ANALYSES OF POTATOES

STARCH CONTENT—The low starch content of southern grown potatoes is a matter of no little importance. In addition to that above stated as to the probable effect of the different potash salts, the analyses of potatoes grown on the Cumberland plateau and of those of series (1) grown in Knox county are noteworthy. From this table it can be seen, first, that the per cent of starch was increased by altitude; second, that it was increased by the use of a complete fertilizer high in nitrogen; third, that it was decreased by the omission of potash from the fertilizer. The explanation of the first of these results is, in part, that the potato is better adapted to the cooler climate of the plateau. Probably the most important reason for the differences between the potatoes grown on the fertilized and the unfertilized plots was in the duration of the life and vigor of the plants. The plants which lived longest and were most vigorous produced potatoes highest in starch; those which died first and were least vigorous, the unfertilized, produced potatoes lowest in starch. According to analyses found in bulletin 57 of the Maine agricultural experiment station spray-

*200 lbs. Acid phosphate.

*200 lbs. Cotton-seed meal.

* 40 lbs. Muriate of potash.

°Since potatoes average only about 0.1 per cent fat this column may be taken to represent the starch content.

ing, which prolongs the life of the plants, increased the starch content by an average of about 1.6 per cent. Therefore, in order to get potatoes of the best quality they should be grown on rich soil, well supplied with moisture, and every effort should be made to prolong the lives of the plants by giving good cultivation and by spraying with Bordeaux mixture, containing Paris green, to prevent both fungous disease and injuries from insects.

FERTILIZER MIXTURES—A great many fertilizer dealers are disposed to urge the farmers to buy ready mixed goods rather than unmixed. In nearly every instance, however, cheaper and better goods can be mixed at home. Moreover, in the last report of the commissioner of agriculture, for 1897-98, no fertilizer is given in the list of those inspected which contained the high percentages of nitrogen, phosphoric acid, and potash found in the mixture used on plot 2, series (1). This mixture would analyze 7.75 per cent available phosphoric acid, 8 per cent potash, and 3.75 per cent ammonia, or 3.1 per cent nitrogen. The materials can be bought at numerous places throughout the state so that a ton of the mixture will cost under $25.00, and they can be mixed in a satisfactory manner on any smooth floor by being shoveled over three or four times. The advantages in mixing are, to be able to apply all at once rather than to make a separate application for each ingredient, and to make the application more uniform.

2 EXPERIMENTS ON CORN

During the past season two series of fertilizer experiments were made on corn. Series (1) was on a typical clay soil of the blue, or Lenoir, limestone formation, which is closely related to the blue limestone of Middle Tennessee. The rock from which this soil originates is sometimes known as rotten limestone from the rapidity with which it disintegrates when exposed to the air. In some sections the soil is known simply as "limestone soil," in others as "red bud land." Series (2) was on a river bottom which is overflowed once in three or four years. The soil would be called a light clay and is well adapted to corn and grass.

SERIES (1)

These experiments were in Knox county on the farm of Mr. W. P. Ford, to whom thanks are due for valuable cooperation. The soil was a heavy yellowish gray clay, low lying and well drained but which occasionally received a light deposit from an overflow of a creek near by. This land had been cropped without fertilizer or manure for about seventy-five years. The prime object of the experiments was to determine the kinds of plant food most needed by this type of soil and which could therefore be used with the greatest likelihood of profit for this particular crop. The chemical analysis showed the soil to be high in total potash, but low both in total phosphoric acid and in nitrogen. The determinations of the available phosphoric acid and potash indicated decided deficiencies of each, and what might be called a secondary object was to have the field experiments test these laboratory results.

No special preparation of the soil was made. The plowing had been done in the fall and the soil was loose and mellow. Great care was taken to select an apparently uniform area, which was laid off into eight 1-40 acre plots. Each plot was 12x90¼ feet, which allowed three rows four feet apart.

APPLICATION OF THE FERTILIZER—With the exception of the nitrate of soda the fertilizer for each plot was applied in broad bands along the rows after the seed had been dropped and lightly covered. All the nitrate was applied at this time and in the same manner as the acid phosphate and potash, but after the seed was fully covered.

CULTIVATION—All the plots were cultivated alike and were kept free from weeds, but received no more than usual attention. In fact, they formed a part of a large corn field and were treated exactly as the remainder of the field.

About the only noticeable effect from any fertilizer during the growth of the crop was that produced by acid phosphate, so that when the plants were young each plot where it had been used was clearly outlined from all the others by its stronger growth. Such a result is one of the best indications of a lack of phosphoric acid in the soil.

TABLE IV RESULTS PER ACRE FROM SERIES (1) OF FERTILIZER EXPERIMENTS ON CORN

Plot	Fertilizer		Yield		Increase from fertilizer		Profit and loss from use of fertilizer*	
	Kind	Lbs.	Corn	Stover	Corn	Stover	Profit	Loss
			Bu.	Lbs.	Bu.	Lbs.		
1	Acid phosphate........	500	52.1	4080	9.3	800	$2.92	......
2	Acid phosphate...... Muriate of potash...	500 200	58.1	4000	15.3	720	......	......
3	Muriate of potash.....	200	39.2	3480	......	200	......	$4.20
4	No fertilizer...........	......	42.8	3280	......	......	......	......
5	Nitrate of soda........	240	60.4	4280	17.6	1000	5.04	......
6	Muriate of potash... Nitrate of soda......	200 240	43.7	3720	0.9	440	......	8.88
7	Acid phosphate...... Muriate of potash.. Nitrate of soda......	500 200 240	60.9	5000	18.1	1720	......	.88
8	Acid phosphate...... Nitrate of soda......	500 240	66.0	5960	23.2	2680	10.00	......

As this soil responded well to both phosphoric acid and nitrogen, samples of corn (kernels) from the different plots were analyzed to determine the effect of the fertilizers on the protein content, an increase of which is highly desirable. The results are as follows:

*The profit and loss is calculated from yield of corn at 40 cents per bushel and the yield of stover at 40 cents per cwt.

Protein content of corn (kernels) from different plots.

Plot	Fertilized with	Per cent
1	Phosphoric acid	10.21
2	Potash	11.36
4	Phosphoric acid and potash	10.35
5	No fertilizer	11.59
	Average for plots not fertilized with nitrogen	10.88
7	Nitrogen	11.80
8	Phosphoric acid and nitrogen	11.66
3	Potash and nitrogen	11.38
6	Phosphoric acid, potash and nitrogen	11.55
	Average for plots fertilized with nitrogen	11.66

Attributing the differences in composition to the effect of the different fertilizers, we see that phosphoric used alone and in a mixture with only potash lowered the protein content 1.3 per cent on the average; that nitrogen used alone slightly increased the protein content, and maintained it when used with the other elements; and that potash was the only element which produced no marked effect one way or the other.

CONCLUSIONS

The results indicate the need of phosphoric acid and nitrogen, both of which were used with profit, as shown in the table. No account was taken of any possible loss by shrinkage of the corn or of the extra expense for the hauling and applying of the fertilizer. The shrinkage would be small as moisture estimations were made of the different lots of corn and in the table they are calculated to the same water content of 15 per cent. On the other hand, where the complete fertilizer was used there would be left in the soil the approximate equivalent of 264 pounds of acid phosphate and 23 pounds of muriate of potash, more than was removed by the total crop. It is to be noted that it would require about 720 pounds of nitrate of soda or 1,560 pounds of cotton-seed meal to replace the nitrogen removed, so that the 240 pounds of the nitrate used furnished only one-third the amount of nitrogen necessary. To maintain the nitrogen supply for this crop by the use of fertilizers alone appears out of the question and demonstrates the necessity of replacing it in the form of stable manure, which means that the crop must be fed on the farm rather than sold off. A very important matter in this connection is a good rotation of crops, in which leguminous plants—peas, clover, etc.—must be prominent. In this way the nitrogen supply can not only be maintained but increased, and the humus supply built up at the same time. Judging from all the chemical analyses of soils made at the station phosphates can probably be used with profit, at least on the majority of the upland soils in East Tennessee and on the soils of the Highland rim, the barrens in particular, and of the Cumberland plateau of Middle Tennessee. Phosphoric acid is the mineral substance which is most deficient and which is of very great fundamental importance. At least enough should be used to more than replace that sold off in the grain crops, and the use of three times this amount for some years to come seems justifiable.

SERIES (2)

These experiments were in Blount county on the farm of Mr R. A. McBath, on what might be called the second bottom of the Little river. This land is usually overflowed once in three or four years, but until about five years ago it produced only thirty to forty bushels of corn to the acre. Since that time a good rotation of crops has been practiced and the yield of corn has steadily increased without the aid of either manure or fertilizer. The experimental plots were in a field which had been in grass and clover for the two previous years. A good sod had been turned under in the winter. In the spring the land was harrowed, cross plowed, and harrowed again, so that it was in excellent condition. As uniform an area as possible was selected and divided into 1-40 acre plots. After rows and check rows four feet apart were laid off to a good depth the fertilizers were applied broadcast, although a somewhat heavier application was made about the hills than at other places. The seed was then dropped in contact with the fertilizer with the result that wherever the muriate of potash or the nitrate of soda was used the germination was delayed nearly a week, while the acid phosphate was without any such harmful action. All the fertilizers were applied at this time except one-half of the nitrate of soda, which was used as a second application when the plants were about two weeks old.

Acid phosphate was the only material which produced any apparent increase of growth in the young plants.

TABLE V RESULTS PER ACRE FROM SERIES (2) OF FERTILIZER EXPERIMENTS ON CORN

Plot	Fertilizer		Yield	+ Unfer- — tilized	Loss from fertil- izer*
	Kind	Lbs.	Corn Bu.		
1	Acid phosphate	500	59.4	+2.8	$2.88
2	Muriate of potash	200	54.9	—1.7	5.00
3	Muriate of potash Nitrate of soda	200 240	49.1	—7.5	11.00
4	Acid phosphate Muriate of potash	500 200	52.0	—4.6	9.00
5	No fertilizer	......	56.6	......	......
6	Acid phosphate Nitrate of soda	500 240	58.3	+1.7	9.32
7	Nitrate of soda	240	58.3	+1.7	5.32
8	Acid phosphate Muriate of potash Nitrate of soda	500 200 240	56.6	......	15.00
9	Acid phosphate Muriate of potash Cotton seed meal	500 200 540	60.0	+3.4	14.39
10	Stable manure	8000	59.4	+2.8	4.88
11	Stable manure	4000	54.3	—2.3	3.00

CONCLUSIONS

This series of experiments is of unusual interest as showing what can be accomplished by a good rotation alone. The results indicate that no

*Calculated only from the yield of corn valued at 40 cents per bushel.

fertilizer or combination of fertilizers was used with any decided increase in yield. We must conclude therefore that the crop was limited by the moisture supply. While the rainfall was below the average and poorly distributed, it is probable that had two or three extra cultivations been given at the right times the crop would have been materially increased. The use of fertilizers on land of this character seems not necessary, provided a rotation of crops be practiced in which cowpeas or clover are frequently grown.

EXPERIMENTS ON COWPEAS

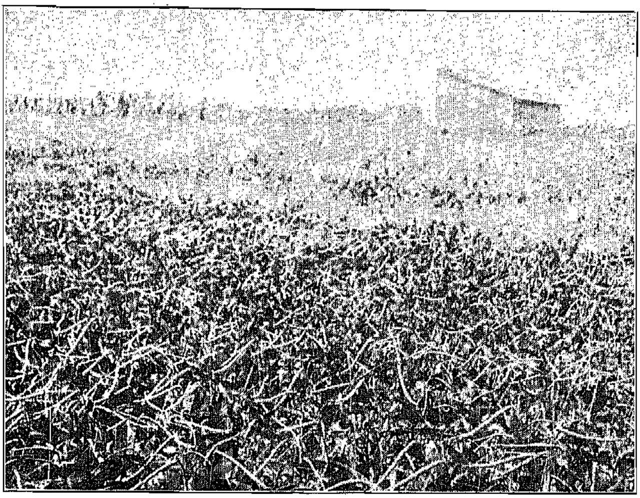
Many agricultural writers advise for leguminous crops on poor land the use of a fertilizer containing a small per cent of nitrogen in order "to give the crop a better start," it being considered that the action of the nitrogen gathering bacteria does not begin immediately upon the sprouting of the plants. One of the poorest soils which has been analyzed by the station, the "white gravelly" used in series (1) on potatoes, was selected to test this point. It was thought that if nitrogen produced no decided increase in the yield on this soil its use would not be warranted on any ordinary soil in the state. A uniform area was selected, plowed to a depth of about seven inches and put in good condition by harrowing. Plots 1-50 of an acre each were laid off and the fertilizer for each, except the nitrate, was then distributed broadcast. The peas were then sown and harrowed into the soil, after which the nitrate was applied. No effect from the fertilizer on the germination of the seed was noted in any instance, the plants on all the plots being up in about three days. At no time during the growth of the young plants was any noticeable effect produced by the nitrogen of either the nitrate of soda or the cotton-seed meal.

TABLE VI RESULTS PER ACRE OF FERTILIZER EXPERIMENTS ON COWPEAS

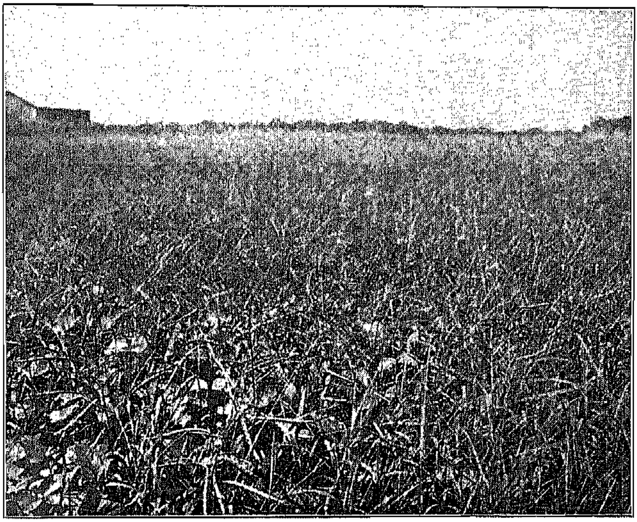
Plot	Fertilizer		Yield				Cost of fertilizers	Profit and loss from use of fertilizer	
	Kind	Lbs.	Peas	Pea hay	Crab grass hay	Total hay		Profit	Loss
			Bu.	Lbs.	Lbs.	Lbs.			
1	Acid phosphate...	500	9.2	1325	712	2037	$ 4.00	$2.29	......
2	Muriate of potash.	200	6.0	1222	100	1322	5.00	......	$2.29
3	Acid phosphate... Muriate of potash.	500 200	8.6	1838	732	2570	9.00	......	.05
4	No fertilizer......	......	3.5	750	30	780	......	......	......
5	Acid phosphate... Muriate of potash. Nitrate of soda...	500 200 25	7.5	1975	1003	2981	9.63	1.38	......
6	Acid phosphate... Muriate of potash. Nitrate of soda...	500 200 150	8.2	1806	1210	3016	12.75	......	1.57
7	Acid phosphate... Muriate of potash. Cotton-seed meal.	500 200 225	9.0	1684	1785	3469	11.81	1.64	......

The profit and loss are calculated from the total hay valued at 50 cents per cwt.

EFFECTS OF FERTILIZERS ON COWPEAS AND CRAB GRASS



Fertilized with Muriate of Potash



Fertilized with Muriate of Potash, Acid Phosphate and Nitrate of Soda

CONCLUSIONS

The results of these experiments were interfered with by the excessive growth of crab-grass, which thrived best in the plots fertilized with nitrogen, although it was markedly increased by the use of acid phosphate and somewhat more by the use of acid phosphate and potash. The plots were kept free from all other weeds. After the hay was cut the crab-grass and pea vines were carefully separated, with the results shown in the table, from which we see that neither the yield of pea hay or peas was increased either by the nitrate of soda or the cotton-seed meal. Whether the yields would have been increased had the crab-grass not been present is clearly not proved. It must be considered, however, that the crab-grass did not make any substantial growth until the peas had been up for some weeks, during which time, as said, no effect from the nitrogen was apparent. The marked effect on the growth of the crab-grass emphasizes the value of nitrogen for such plants as millet or sorghum when grown with peas. The effect of the mixture of acid phosphate and potash on the pea crop was very marked, producing an increase of 146 per cent of peas and 163 per cent of pea hay. From these experiments on soil which is very poor in potash as well as phosphoric acid we would judge potash to be much less needed for this crop on Tennessee soils than acid phosphate, which is most highly recommended for all soils of like character. In this class we would also include in particular the soil of the Cumberland plateau and of the "barrens." Though not entirely satisfactory, the results of these experiments when compared with the results obtained at different places do not warrant for this crop the use of a fertilizer containing nitrogen, whether in such a quick acting form as nitrate of soda or in the slower acting bone meal and tankage. The question seems thus to be narrowed down to phosphates or phosphates and potash, so that simple experiments which every farmer should make will determine which if either can be used with profit.

EXPERIMENTS ON PEANUTS

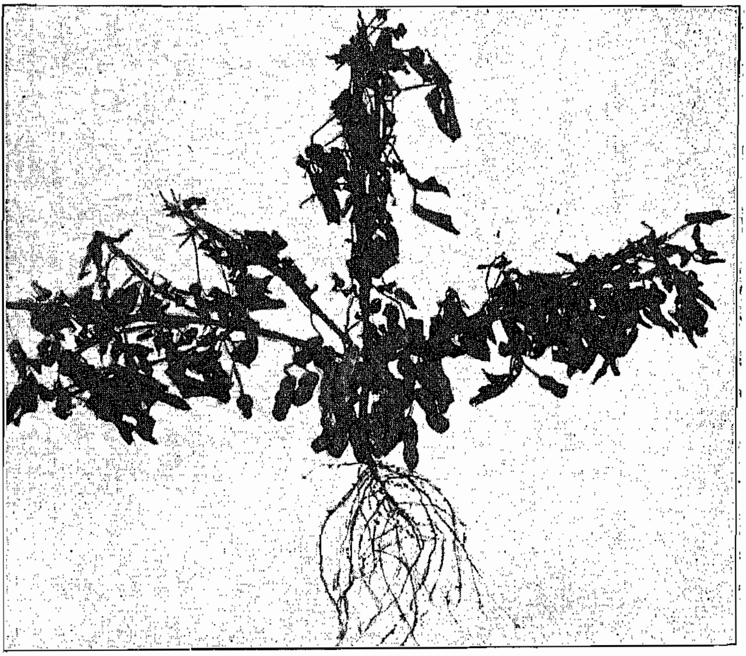
No systematic series of experiments were made on peanuts, but practically the same object was in view as in the experiments on cowpeas; that is, to determine whether the use of a fertilizer containing nitrogen is justifiable. The same soil was used for these experiments as for those on cowpeas. The peanuts were planted about two and one-half feet apart in rows three feet apart. In one set of experiments acid phosphate at the rate of 500 pounds to the acre and muriate of potash at the rate of 200 pounds to the acre were applied in the rows and mixed with the soil by running a single shovel plow through it once. In another set, acid phosphate and muriate of potash were applied at the same rates, but mixed with them was dried blood at the rate of 350 pounds to the acre. In a third set tankage containing approximately 10 per cent of phosphoric acid and five per cent of nitrogen was used at the rate of 700 pounds to the acre to take the place of the acid phosphate and the blood of the preceding experiment. Frequent cultivations were given throughout the season, so that the soil was kept loose and clean.

TABLE VII RESULTS PER ACRE OF FERTILIZER EXPERIMENTS ON PEANUTS

Plot	Fertilizer		Yield		Per cent hulls in salable nuts
	Kind	Lbs.	(a) Salable nuts	(b) Culls	
			Lbs.	Lbs.	
1	Acid phosphate Muriate of potash	500 200	880	125	28.8
2	Acid phosphate Muriate of potash Dried blood	500 200 350	888	150	31.7
3	Blood and bone Muriate of potash	700 200	753	152	Not determined

CONCLUSIONS

From the table it may be seen that the yield was practically the same whether the plants were fertilized with or without nitrogen. Phosphoric



PEANUT PLANT (RED) SHOWING NODULES ON ROOTS

acid from acid phosphate produced a much better yield than from tankage. The proportion between hulls and kernels show that the blood caused a thicker growth of hull and to this extent therefore acted in a detrimental manner. If on this exceedingly poor soil no advantage was gotten from nitrogen, the use of this element in a fertilizer for peanuts seems unwarranted. Fertilizer experiments on leguminous plants in general point to the same results. We would conclude therefore that leguminous crops take away from the soil fertility only so far as the mineral elements, phosphoric acid and potash, are concerned but in this respect they are very exhausting. The continued growth of peanuts where the tops are removed for hay undoubtedly decreases the soil's supply of humus; to maintain which a rotation of crops should be practiced and either green crops or manure should be occasionally turned under. Lime is often looked upon as particularly essential to the peanut crop, but it must be remembered that approximately one-half of acid phosphate may be considered to be land plaster, the sulphate of lime, and that the phosphoric acid is combined with lime. On Tennessee soils the use of lime alone for peanuts is not especially recommended, but when used with phosphates quicklime may be beneficial by correcting excessive acidity of the soil and by improving its texture. The same remarks apply to clover which does not thrive on an acid soil or on one deficient in phosphates or potash.

TABLE VIII SOIL ANALYSES

	(1) For series (1) on corn	(2) For experiments on cowpeas, peanuts, and for series (1) on potatoes
	Per cent.	Per cent.
Insoluble matter	86.11	89.23
Potash (K_2O)	0.43	0.14
Lime (CaO)	0.22	0.09
Magnesia (MgO)	0.24	0.11
Ferric oxide (Fe_2O_3) } Alumina (Al_2O_3) }	7.65	6.01
Phosphorus pentoxide (P_2O_5)	0.077	0.03
Volatile matter	5.20	4.23
Humus	2.45	1.80
Nitrogen	0.12	0.079

	(1) Per cent.	(2) Per cent.
Phosphorus pentoxide (P_2O_5) soluble in 1 % citric acid	0.0023	0.0021
Potash (K_2O) soluble in 1 % citric acid	0.0042	0.0081

A chemical analysis which gives the total amounts of plant food in a soil is chiefly valuable for showing any marked deficiency in one or more elements or on the contrary for indicating abundant supplies of plant food which can be drawn upon, so that, in either case, it is of great assistance toward founding a rational system of manuring and cropping.

In chemical composition soil (1) is a representative of a large number of Tennessee soils, which as a rule analyze comparatively highly in potash, but tend to run low in phosphoric acid (phosphorus pentoxide), lime, and nitrogen. Theoretically, with conditions of texture, depth of soil, etc., favorable, such soils can be economically brought to a state of fertility far beyond the present by the use of phosphate as the only commercial fertilizer and by practicing a rotation of crops in which legumes are prominent.

Soil (2) is a good representative in chemical composition of the "cherty" dolomite ridges of East Tennessee, and with a higher per cent of potash but a still lower per cent of phosphoric acid, would represent the soils of the Cumberland plateau and of the "barrens." If the use of phosphate and the growing of leguminous crops be important for the more durable and fertile soils of the state, they should be considered as necessaries in these naturally poorer sections. The soils of the cherty dolomite ridges are capable of being made highly productive and durable by reason of their good depth and texture, which is favorable to the retention of both plant food and moisture. In addition to phosphoric acid the analysis indicates this soil to be low in potash, both of which conclusions the field experiments justify.

The small amount of phosphoric acid and potash soluble in 1 per cent citric acid solution indicated for both soils decided deficiencies of immediately available plant food, but like fertilizer experiments of a single season these results throw but little light on the question of the best policy to be pursued year after year.

EFFECTS OF FERTILIZERS ON THE GERMINATION OF SEED

Nearly all fertilizer materials have a harmful effect by delaying or even entirely preventing the germination of the seed with which they are in contact*. For this reason, fertilizer applied in the row is usually mixed with the soil before the seed is dropped or it is applied after the seed has been lightly covered, and if a more general distribution be desired it is drilled or applied broadcast and harrowed into the soil so that it will not touch the seed. When any of these methods were used no appreciable delay in the germination took place, and this was also true in the case of cowpeas sown broadcast on to the fertilizer, after which both were harrowed under. In series (2) on corn the effect on the germination of the seed brought into contact with the fertilizer, which had been applied somewhat more heavily on and about the hills than elsewhere, was carefully noted by Mr Horace McBath, who furnished the data for the following report.

The date of planting was May 3. On the 8 there was a light shower and on the 10 the corn was beginning to come up. The percentage of hills missing for each of the plots on the 11 and later on the 18 of the month is shown in the table.

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*See Bulletin 24 (1900) U. S. Dep. of Agr. Div. of Botany.

TABLE IX EFFECT OF FERTILIZERS ON THE GERMINATION OF CORN

Plot	Fertilizer: Kind	Fertilizer: Rate per acre	Per cent. hills missing, May 11	Per cent. hills missing, May 18
		Lbs.		
1	Acid phosphate	500	8	0
2	Muriate of potash	200	79	1
3	Muriate of potash Nitrate of soda	200 240	85	2
4	Acid phosphate Muriate of potash	500 200	80	1
5	No fertilizer	....	8	0
6	Acid phosphate Nitrate of soda	500 240	54	1
7	Nitrate of soda	240	53	0
8	Acid phosphate Muriate of potash Nitrate of soda	500 200 240	96	4
9	Acid phosphate Muriate of potash Cotton-seed meal	500 200 540	76	1

The experiments show that acid phosphate was the only material which had no noticeable effect on the seed, and that both muriate of potash and nitrate of soda delayed the germination to a marked extent. While in this case the final effects were not serious, under more unfavorable conditions they might have been otherwise. The safe plan therefore is to mix the fertilizer with the soil before planting or to drill it out of contact with the seed. For wheat, however, the fertilizer is at present nearly always drilled with the seed, so that only a limited amount of any quick acting material can be used without the risk of serious consequences. To test this question some of the most frequently used fertilizer materials were drilled at different rates along with wheat at the rate of one bushel to the acre. The date of drilling was November 17. Though late in the season, the conditions of weather and of soil moisture were favorable to germination, so that within a week the seed on the unfertilized plot was beginning to come up.

The following table gives the results on December 1, two weeks after seeding:

TABLE X EFFECT OF FERTILIZERS ON THE GERMINATION OF WHEAT

Plot	Fertilizer — Kind	Fertilizer — Rate per acre	Per cent. germinated in two weeks
		Lbs.	
1	No fertilizer	....	85.7
2	Cotton-seed meal	50	20.3
3	Cotton-seed meal	100	none
4	Cotton-seed meal	150	none
5	Cotton-seed meal	200	none
6	Cotton-seed meal	250	none
7	Acid phosphate	200	76.8
8	Acid phosphate	250	76.8
9	Tankage*	200	85.7
10	Tankage*	100	85.7
11	Tankage	200	39.3
12	Tankage	100	39.3
13	Nitrate of soda	25	67.9
14	Nitrate of soda	50	53.6
15	Nitrate of soda	100	none
16	Muriate of potash	25	67.9
17	Muriate of potash	50	53.6
18	Muriate of potash	75	39.3

In these experiments acid phosphate was the only material drilled with the seed without decidedly serious effects on the germination. Just how much permanent injury was done by the other materials can not now be told, but the results are sufficient to demonstrate that the present practice of drilling the fertilizer in direct contact with the seed is wrong in principle and needs correction. Wheat growers have been slow to recognize this because the 100 pounds of fertilizer so generally used seldom contains more than six pounds of muriate of potash, and 40 pounds of tankage, the remainder being acid phosphate. In fact, the opinion is current that the fertilizer hastens the germination and so gives the wheat a better start. On the other hand, the complaint is often made that the "high-grade" fertilizer which contains 3 to 4 per cent ammonia and 4 to 5 per cent potash does not give the wheat as good a start as the "low-grade" fertilizer which contains no ammonia, and the statement is often heard at farmers' institutes that doubling the amount of fertilizer did not seem to increase the yield. The results from plots 8 and 9, where the fertilizer and seed were drilled separately, show that if the fertilizer be a little removed from the seed no harm is done and only good results would be expected.

While the lateness of the season when the tests were made would favor slow germination and so increase the danger other experiments made the latter part of October verify the main conclusions. In these earlier experiments a mixture of 300 pounds of cotton-seed meal, 300 pounds of acid phosphate, and 75 pounds of muriate of potash was applied broadcast but not harrowed into the soil, without effect on the germination of wheat

*Seed and fertilizer drilled separately.

drilled immediately afterward, while a mixture of 140 pounds of acid phosphate, 100 pounds of cotton-seed meal, and 25 pounds of muriate of potash drilled with the wheat on the same day so affected the germination that at the end of six weeks, when the last examination was made, only 82 per cent, as much had come up as where no fertilizer was used, and although the soil was deficient in plant food, the unfertilized wheat had made an apparently stronger growth than the fertilized.

The results are such that the following conclusions seem warranted: First, that there is need of an improved grain and fertilizer drill which will put the fertilizer either beneath the seed or to one side of the seed so that in either case the fertilizer and the seed will be separated by a layer of soil; second, that of the nitrogenous fertilizer mixtures sold on the market only those which contain slow acting sources of nitrogen, such as low-grade tankage or bone, can be safely drilled in contact with the seed of the small grains and then only in limited amounts; third, that potash salts and the quicker acting and more desirable sources of nitrogen, such as cotton-seed meal, blood and nitrate of soda, and in general, large amounts of any fertilizer can not safely be used in contact with the seed.

It should be added that no experiments were made with bone meal used alone, but it is not improbable that with the possible exception of acid phosphate, more of this material can be safely used than of the other materials tried.

SUMMARY OF RESULTS OF FERTILIZER EXPERIMENTS DURING 1900

POTATOES

1 The most profitable returns came from a complete fertilizer containing high percentages of all three elements, nitrogen, phosphoric acid, and potash.

2 As a source of nitrogen, cotton-seed meal gave in every instance more profitable returns than nitrate of soda.

3 Nitrate of soda mixed with cotton-seed meal was not profitable.

4 Potatoes fertilized with nitrogen, phosphoric acid, and potash averaged 2.74 per cent higher in starch than the unfertilized and one per cent higher than those fertilized with nitrogen and phosphoric acid without potash.

5 Potatoes grown on the Cumberland Plateau averaged 0.79 per cent higher in starch than those grown in the Tennessee Valley.

CORN

1 The yield of corn grown on river bottom land where a rotation of corn, oats, clover, and grass had been practiced was not profitably increased by any kind of fertilizer.

2 The yield of corn on land which was of more than average productiveness but which had been cropped in corn and small grains consecutively for many years was profitably increased by heavy applications of acid phosphate and nitrate of soda.

3 The need of phosphoric acid was demonstrated more clearly than that of any other element.

4 The grain from plants fertilized with nitrogen averaged higher in nitrogenous substance (protein) than that from plants fertilized only with the mineral elements, phosphoric acid and potash.

COWPEAS

1 On exceedingly poor soil nitrogen was not found of any advantage so far as the yield of either peas or hay was concerned, but gave a marked increase in the yield of the crab-grass which grew among the pea vines.

2 Phosphoric acid used alone produced a larger yield of the peas (fruit) than when potash was used with it.

3 Phosphoric acid and potash produced a larger yield of hay than the phosphoric acid alone.

4 Potash used alone was not profitable.

PEANUTS

Nitrogen when added to phosphoric acid and potash did not increase the yield but lowered the grade of the nut by producing a thicker hull.

GERMINATION OF SEED

1 Fertilizers have a decidedly unfavorable effect on the germination of seed so that they can seldom be safely used in direct contact with the seed.

2 The present method of drilling the fertilizer with the wheat is highly unsatisfactory by preventing the safe use of even moderate amounts of high grade fertilizers, which contain cotton-seed meal, blood, tankage, nitrate of soda or potash salts.

GENERAL CONCLUSIONS

1 Every farmer should make fertilizer experiments to determine the special requirements of his soil.

2 Every farmer should make his own fertilizer mixtures to suit his soil and crop.

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